Report of the Senior Review

of the Astrophysics Division

MISSION OPERATIONS AND DATA ANALYSIS (MO&DA) PROGRAMS

April 26-28, 2006

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Introduction

The 2006 Senior Review of the Astrophysics Division Mission Operations and Data Analysis (MO&DA) Programs was conducted on April 26-28, 2006. The Review Panel considered the currently operating missions, which are reviewed every two years. The Data Archives and Service Centers, last considered by the 2004 Senior Review, are only reviewed every four years. The Panel reviewed proposals for minimal and optimal budgets from eight currently operating missions for fiscal years FY07-08, with preliminary consideration also being given to FY09-10. All of the missions are carrying out high quality programs that are fully consistent with NASA's goals and science priorities as described in the 2006 NASA Strategic Plan, objective 3D, and with prior (2003) and current draft Astrophysics Division roadmaps. However, in the current budget climate difficult prioritizations had to be made, especially for fiscal years 2009 and 2010 when the projected budget shortfall is most acute and the Panel was constrained to recommend funding some missions at less than their proposed minimal level.

The eight missions under consideration were NASA's five currently operating Explorer-class missions: the MIDEX-class RXTE, FUSE, WMAP and Swift missions and the SMEX-class GALEX mission, along with the ESA-NASA Observatories INTEGRAL and XMM-NEWTON, and the JAXA-NASA Suzaku mission.

Since the primary issue under consideration by the Panel was the future funding of these missions, they were ultimately ranked on a combination of their anticipated science, and science per dollar, returns. The annual costs of the missions were broadly bimodally distributed, but differed overall by at most a factor of 3, which was significantly less than in the previous Senior Review, making the process less sensitive to the precise balance between these two factors.

The Review Process

As for previous Reviews, the missions were requested to submit proposals describing their science goals for the next two and (up to) four years, and to provide associated minimal and optimal budgets. The 2006 Senior Review Panel consisted of 12 scientists, 5 of whom (including the Chair and past Chair) had served on the 2004 Senior Review. We were asked to provide budget and mission-program findings for FY07-08, and initial responses for FY09-10 which may be reconsidered by the 2008 Senior Review.

The first day and a half of the Review were occupied by presentations by the individual missions, allowing them to update their proposals (submitted one month previously) and the Panel to ask questions about critical proposal details. In one case an external written review of a proposal was also solicited ahead of the Review to augment the expertise of the Panel, although in practice the reviewer's comments were very similar to those of the Panel.

A preliminary ranking of the missions identified the most contentious areas for further discussion, after which a first-pass budget proposal was drawn up. Over the next day this process was iterated and refined to produce the rankings and findings presented here. Final rankings, on a scale of 1-10, had dispersions between 0.3 and 2.2, but were typically of order unity.

The Panel had a number of process-related recommendations for future Senior Reviews, both for proposing missions and NASA HQ staff:

1. The Panel reiterates its request that proposals explicitly address any recommendations made by the previous Senior Review. Given how many missions continue to ignore this (or at least do not make it clear in their presentations, written or oral, how they have complied), we recommend that this be a **required** section in proposals in future Senior Review cycles.
2. In line with this, we suggest that in the off years between Senior Reviews NASA HQ staff should follow up on any such recommendations, pressing missions to comply with them wherever possible, and negotiating alternatives which preserve as much of the spirit of the recommendation as possible when circumstances reasonably prevent full compliance.
3. Generally the budgets were more coherent than in previous Reviews, and we strongly encourage missions to provide their budget information exactly in the template provided. We suggest that NASA make minor revisions in the budget template to make it even more clear what the separate budget lines are for Guest Investigator (GI) grants vs. support of the GI program as well as Science Team data analysis. In addition, we found that it would be very useful for missions to present, within their proposals, the FTE equivalents (and the associated 5-way functional breakouts) corresponding to their minimal and optimal budgets.
4. The Panel encourages NASA missions to consider accepting Guest Investigator proposals for modeling and interpretation investigations in addition to the more standard data reduction and analysis investigations. The Panel suggests to NASA that the fraction of GI support for such modeling and interpretation studies (which must be relevant to data from the mission at hand) be limited to 3-5% of the total GI program for a given MIDEX class (or larger) mission, as was recommended in the 2001 Decadal Survey Report. While it is outside of our immediate brief, the Panel wishes to express its grave concern that the ATP and ADP programs that support general theory and data analysis are currently critically under-funded.
5. Proposing missions should be advised that generic supporting testimonials are at best irrelevant and at worst counter productive.

MISSION ASSESSMENTS

(in rank order, from highest to lowest in overall rank)

Swift

The Swift mission, a MIDEX-class Explorer launched in November 2004, is operating smoothly and carrying out a highly successful mission to study Gamma-ray Bursts (GRBs) as well as conduct a hard X-ray sky survey and studies of transients and other targets of opportunity (TOO). Swift is an Observatory-class mission, with 3 primary instruments (BAT, XRT and UVOT) on a novel spacecraft that can execute rapid (~100 sec) slews to point at GRBs autonomously or TOOs by prior command. Its combined optical, X-ray and hard X-ray coverage is not duplicated by any other mission.

Spacecraft/instrument health & status:
The overall mission health is excellent. The BAT has experienced occasional detector problems, but is operating in GRB detection mode over 98% of the time. The XRT lost its thermoelectric cooler early in the mission but CCD sensitivity is maintained by control of spacecraft orientation and solar heating management. The CCD for the XRT suffered a micrometeorite hit resulting in a <1% loss of detector area. The UVOT has functioned nominally after early mission adjustments. The spacecraft and ground data processing and distribution systems have functioned smoothly.

Science strengths:
Swift has already precisely located more GRBs (>120) than all previous GRB missions combined. In its first year it achieved two major mission goals: localization of the first short GRBs and identification of their hosts with old stellar populations (most likely neutron star - neutron star mergers); and detection of the highest redshift GRB yet recorded (at $z = 6.3$). The mission is on its way to fulfilling its promise both to decipher GRBs and to use them as cosmological probes of the early universe. In addition numerous (>155) galactic accretion powered sources (X-ray binaries, CVs and transients) and >150 AGN were detected and in many cases discovered in the course of the BAT survey over the first year. Some 120 non-GRB TOOs have been observed in the first year of operation by request to the mission PI.

The mission is breaking new ground. Not only is it the first to open the domain of high time resolution/wide field astronomy, but it has also shown how an Observatory-class, multi-instrument mission can be done under the Explorer envelope with the aid of international collaboration. The overall costs are reasonable for a mission of this complexity.

Relevancy strengths:
Swift is conducting studies of black holes that are directly relevant to the longer term and more ambitious goals of the Black Hole Finder Probe in the Beyond Einstein program. Mission management and operations planning are also setting new examples for efficiency.

Data accessibility:
The Swift policy of 100% open and immediate access to full raw and processed data and full analysis software is setting a new standard for NASA missions.

Proposal weaknesses:
The proposal budget request, while reasonable, may be too low in its request for GI funding (even for the recommended optimal budget). This level of funding would support just 60 GIs with $30K grants, whereas when pointed observations are opened to GIs in cycle 4, it is likely that the number of proposals will greatly exceed this number. Likewise, it is not clear why in later years (FY09 and beyond) Mission Operations and Science Center functions could not be reduced gradually as the mission becomes increasingly automated.

Overall assessment and recommendations:
The Panel ranked Swift as the highest priority mission under review and recommends that it be funded at the proposed optimal budget level.

GALEX

The Galaxy Evolution Explorer, a NASA Small Explorer UV survey mission, is in its third year of operations. The scientific return from GALEX is outstanding. GALEX is revolutionizing our understanding of the UV sky and critically informing our understanding of star formation and galaxy evolution in the local universe. The GALEX team has done an extraordinary job on a tight budget delivering enormous science results and returns to the community. Two areas of concern are (1) problems experienced with the FUV detector, contributing to a delay in completing the baseline mission survey science, and (2) the long turnaround time for data through the calibration pipelines.

Spacecraft/instrument health & status:
Overall mission health is good. Flight and ground systems are performing very well, with no cause for future concern. The near UV detector performance meets preflight expectations and is stable. The far UV detector has had problems (the HV-current anomaly and an elevated diffuse background "blob") but these have both been mitigated by HV cycling. This has now been instituted as an automated monthly preventative process with no loss of observing time.

Science strengths:
As the first all sky UV imaging (and spectroscopic) survey mission, GALEX is returning impressive and unique scientific results, uncovering dramatic new results on the nature, origin, and evolution of star formation (and hence galaxy formation and evolution) in the nearby universe and the nature of the UV sky. The mission is performing very well overall. The GALEX survey archive is providing a treasure trove for understanding the UV sky, and provides a critical dataset to inform and complement SPITZER, HST, and Chandra observations. The completion of the Prime Mission Surveys and the Extended Mission surveys are critical to the full scientific return from GALEX. The promise for continued high quality scientific returns from GALEX is high.

Relevancy strengths:
GALEX is making critical contributions to our understanding of star formation and galaxy evolution, both central to NASA's Astrophysics Division goals.

Data accessibility:
Processed and calibrated GALEX data and high-level associated science products are available through the MAST archive. The delay in processing of GALEX data and its inclusion in the MAST archive is currently considerable and negatively impacts the scientific returns from the mission.

Proposal weaknesses:
The FUV detector on GALEX has experienced significant operational problems. Although the GALEX team has taken heroic and effective steps to assure quick recovery from FUV detector incidents, these problems have inhibited the completion of the prime mission survey science and create risk for the future. While the NUV detector provides significant scientific returns in its own right, it is clear that the loss of the FUV Detector would very significantly impact the scientific returns of the mission. The GALEX proposal includes funding for an archival GI program. While recognizing the enormous science value of the GALEX archive, the funding to support archival research for GALEX, as all other missions in this review, should be part of the ADP grant funding. We recommend that the funding levels for ADP to support archival data analysis from GALEX (and other missions) be kept high to realize the full scientific returns from currently operating (as well as past) missions.

Overall assessment and recommendations:
GALEX is returning excellent science and producing a legacy dataset on the UV sky. The completion of the prime mission survey science is critical to realizing the full scientific return of GALEX. Rapid completion of this science should be given the highest priority, to assure its completion while the FUV detector is operating optimally. The proposed extended mission surveys also promise excellent scientific returns. The Panel feels that completion of the survey science and rapid delivery of calibrated science products to the scientific community are the highest priority for the GALEX mission. We note that for the community to realize the full benefit of GALEX in synergy with HST, Spitzer and Chandra it is critical that the data products from GALEX be made available to the community in a timely manner. We therefore recommend that the GALEX mission focus resources on automation of its pipelines to assure rapid delivery of calibrated data and associated data products to the community. In view of the risk associated with the FUV detector, we recommend that the observations for the primary all-sky survey and legacy surveys be loaded into the schedule as soon as practical, and that GI time only be ramped up as the completion of these surveys allows. Specifically the Panel would be comfortable with a low fraction (e.g. 15-25%) of GI science time in the immediate future in order to assure that the primary scientific goals of the survey science are achieved.

We recommend funding at the optimal budget level in FY07-08 in all areas except the GI program, in line with its relative priority as recommended above. Consideration may be given to increasing the GI related funding in years FY09-10 at the next Senior Review.

XMM-Newton

XMM-Newton is a cornerstone mission of ESA's Horizon 2000 program and is comparable in scope to a NASA Great Observatory. XMM has three co-aligned X-ray telescopes and a UV/optical monitor (OM). NASA-sponsored teams contributed to the reflection gratings mounted on two of the telescopes and the OM. The XMM Guest Observer program is open to US scientists with ~40% of the accepted

proposals having US Principal Investigators and an additional ~25% with US co-Investigators. Roughly 250 papers per year use XMM data and these papers are typically well cited.

Spacecraft/instrument health & status:
The XMM-Newton spacecraft and instruments are in good condition. Early in the mission, two of the 18 CCDs in the RGS failed and the OM was found to have a stray light problem and reduced UV sensitivity. Roughly 30% of the total observing time is contaminated by background flares due to soft protons. During March 2005, a micrometeorite hit one of the seven CCDs in the EPIC MOS1, causing it to fail; fortunately this was not the on-axis CCD.

Science strengths:
XMM has made many important scientific contributions on topics such as clusters of galaxies, relativistic iron line emission from active galactic nuclei, supernova remnants, X-ray binaries in other galaxies including ultra-luminous X-ray sources, isolated neutron stars, pre-main sequence stars, and even planets within our own solar system. The observing program for XMM is very highly oversubscribed, by a factor of seven. Looking forward, we anticipate a strong scientific return from continuing observations with XMM, and from mining the growing XMM archive including the recently implemented slew survey. The team has done a good job in reducing the costs associated with the instrument teams. A significant fraction of the total budget is devoted to the GO program, which allows a reasonable level for support for individual investigators.

Relevancy strengths:
XMM observations directly address NASA scientific objectives in the areas of cosmology and of extreme gravitational and magnetic fields.

Data accessibility:
X-ray data access via the HEASARC is straightforward and well understood by the community. The US Guest Observer Facility (GOF) has added value by producing the "ABC Guide" and improving the proposal submission software. The XMM team has significantly improved access to OM data, which are now available as images and source lists with astrometry corrected to 1 arc second in the HEASARC and MAST. The team is commended for directly addressing this issue raised in the 2004 Senior Review.

Proposal weaknesses:
The 2004 Senior Review requested that the project “prepare a plan for operating the program with significantly reduced budgets in later years.” Although instrument team support was appropriately reduced, and theory (**) and archival research support was removed, the overall budget request was above even that proposed in 2004. Despite the strength of the science of this mission, this failure to address prior concerns should not go unremarked. It also seems that some of the software development being funded by the GOF goes beyond that directly required for support of the mission. (** The Panel notes that XMM proposal selection is done by an ESA-sponsored peer review and is thus outside the control of our recommendation #4 above for limited support for “modeling and interpretation” studies.)

Overall assessment and recommendations:
XMM-Newton is an extremely valuable resource. The scientific output of US observers on XMM is very high and is accomplished with a relatively low investment of NASA funds. The capabilities of

XMM complement those of other X-ray observatories such as the Chandra X-ray Observatory, the Rossi X-ray Timing Explorer, and Suzaku. We recommend that this program continue at the proposed minimal funding level in FY07-08, but to plan for a reduction in the GI program in FY09-10.

WMAP

The Wilkinson Microwave Anisotropy Probe (WMAP) is a MIDEX mission designed to provide all-sky maps at five microwave frequencies (23, 33, 41, 61 and 94 GHz) with high sensitivity and precision. The WMAP team released the results of their first year of observations, including all-sky temperature maps and TT and TE power spectra, in February 2003 to considerable media interest. Results from the first three years of operation (to September 2004) were released in March 2006, again to considerable interest.

Spacecraft/instrument health & status:
Mission operations at L2 remain extremely smooth and reliable. Three high-energy particle encounters triggered planned safe-mode shutdowns with subsequent complete recovery. One battery cell failed early on: more than sufficient battery capability remains. There are no consumable cryogens, and fuel reserves are more than adequate.

Science strengths:
WMAP addresses fundamental scientific questions in a way that is, at present, uniquely complementary to other observations. The three year results present updated all-sky temperature and the first all-sky polarization maps, their associated TT, TE and now also EE power spectra, and constraints on fundamental parameters of cosmology derived from these data both alone and in combination with other cosmological observations. WMAP results are heavily used by the astronomical community, and continue to be a high impact public relations benefit for NASA. Continued operation should improve the accuracy of constraints on cosmological parameters (particularly the optical depth to reionization and the tensor to scalar ratio), provide better input to the calibration of suborbital CMB observations, and enhance our knowledge of Galactic emission, including providing low-frequency foreground templates for future CMB satellite missions.

Relevancy strengths:
WMAP continues to be fundamentally relevant to the Astrophysics Division 2003 roadmap objectives 1, 3, and 4, and to the 2006 NASA strategic objective 3D.

Data accessibility:
Data are archived and distributed through LAMBDA, which was established to be NASA's central CMB data archive and distribution center. As with the 2004 Senior Review, there are still concerns about the release of data products to the community in a timely manner. This is important because WMAP has no GO or GI program other than such releases.

Proposal weaknesses:
WMAP has already been operating for 4.5 years and will reach 6 years on its current funding commitment. The argument for this current extension proposal should therefore have concentrated on the science return from 8 years of data versus 6 years. Instead, the proposal compared 8 years to 3

years, leading to considerable speculation by the Panel about what the improvement of 8 years over 6 years would really be. The case for 8 years versus 6 seemed to rest on statistical reduction of error bars, on better understanding of Galactic foreground emission, and on the possibility that increased signal to noise might bring qualitative improvements in the control of systematic errors. But this was not clearly demonstrated in the proposal.

Although the proposal did contain a section discussing why it took so long to release the data, the Panel was concerned that the recommendations of the 2004 Senior Review for both annual and complete data releases were not explicitly addressed. The need to be very careful not to release erroneous or misleading data was well appreciated, but the proposal failed to acknowledge that Senior Review concerns were worth addressing.

The case for an extension was not placed in context. Planck was mentioned and it was claimed (without evidence) that it would not be able to control its systematic errors as well as WMAP has. Smaller scale CMB measurements were mentioned, but mostly just to argue that they required WMAP for calibration. Sub-orbital experiments planning to constrain the B-modes at degree scales (where their anticipated inflationary gravity-wave induced anisotropies are expected to peak) and smaller (where they will far exceed WMAP's ability to detect a gravitationally-lensed E-mode contribution) were not mentioned at all.

Overall assessment and recommendations:
This remains high-profile science of value for the future. Although forthcoming experiments, including ground-based, sub-orbital, and space-based projects, may address some questions better than WMAP, nevertheless WMAP is an operating, stable, understood, mission, with a unique low frequency band. The team has done an excellent job of reducing their requested budget, much more in consonance with the guidelines than most other proposals. Funding is well leveraged, e.g. by LAMBDA support for WMAP data reduction and archiving and by team members with other funding support (notably NSF).

We recommend continued funding of WMAP at their requested minimal budget level in FY07 and FY08 (which would provide 7 years of data), and cautiously endorse continuation in FY09 to complete the mission with 8 years of data collection. Operations until FY09 are subject to the team demonstrating in their next Senior Review proposal that a 5 and/or 6 year dataset have achieved the anticipated reduction in statistical and systematic errors beyond the 3 year data. Funding should then ramp down in FY10 (as proposed) to permit the completion of the data analysis and release of the final data products.

INTEGRAL

INTEGRAL is a gamma-ray mission consisting of four instruments, SPI (20 keV – 8 MeV), IBIS (15 keV – 10 MeV), JEM-X (3 – 35 keV), and the OMC (V band). The X-ray and gamma-ray instruments use coded mask imaging. INTEGRAL was launched 17 October 2002 as an ESA cornerstone mission. ESA has approved extending the mission through 2008, with a further recommendation for an extension through 2010. NASA support of the INTEGRAL mission in partnership with ESA helps to provide access to unique data at reasonable cost.

US PIs won 70 observation proposals in Cycles 1 – 3, representing 26% of the total. Some 15% of INTEGRAL publications have first authors from the US. There were 160 proposals in AO3, of which 85 were approved, with a fourfold oversubscription in time. In AO4, 145 proposals were received, with 8x oversubscription in time. INTEGRAL has detected 210 sources, of which 56 are new IGR sources, and 68 are AGNs.

Spacecraft/instrument health & status:
The instrument has been functioning well, though SPI suffered loss of 2 out of 19 detector modules, representing an approximately 10% loss of efficiency. JEM-X lost a dozen microstrip anode elements and is operating at reduced efficiency, with only one of the detectors operating at a time. The high-energy instruments did not reach pre-launch expectations because of larger background than expected. No serious instrument degradation has occurred since the previous review.

Science strengths:
INTEGRAL has produced important new results on maps of the 0.511 MeV positron annihilation line and the 1.809 ^{26}Al line, and has detected the 67.8 keV ^{44}Ti line and the 1.173, 1.133 MeV ^{60}Fe lines. These observations have fundamental importance by tracing nucleosynthesis from stellar explosions throughout the Galaxy. They have discovered a large number of new Galactic X-ray transients as well as obscured X-ray pulsars, and produced new results on SGRs, SNRs, and GRBs. It is the only mission now and in the foreseeable future that provides information on the nuclear gamma-ray sky. One of its key projects is to provide uniform deep exposure of the Galactic plane.

Relevancy strengths:
INTEGRAL observations are directly relevant to the Lifecycles of Matter goals of NASA's original Structure and Evolution of the Universe roadmap as well as current Astrophysics Division science objectives.

Data accessibility:
The early data analysis software was difficult to use, but the more recent software releases from the INTEGRAL-GOF at GSFC provide better usability. This answers one of the recommendations of the 2004 Senior Review. INTEGRAL has useful synergy with many other missions. INTEGRAL is the only mission in the foreseeable future to provide sensitive coverage in the nuclear gamma-ray line region of the electromagnetic spectrum.

Proposal weaknesses:
INTEGRAL's data analysis software was very user-unfriendly at the beginning of the mission, slowing the output of results. The proposal did not make clear what further steps could be taken to improve data access and ease of analysis. The number of proposals in AO4 was fewer than in AO3, even though time-oversubscription has increased. Outreach to larger community needs to be improved.

Overall assessment and recommendations:
Because of the uniqueness of the data set and the access of US scientists to a mission where the bulk of the costs are borne by ESA, the Panel recommends supporting this proposal at the in-guide level for FY07-08. The Panel also recommends funding at somewhat below the in-guide level in FY09-10, provided that the mission is extended by ESA.

Suzaku

The joint Japanese-US mission Suzaku, a major new X-ray observatory, was launched in July 2005 to conduct high spectral resolution studies of cosmic x-ray sources over a broad band (0.2 – 600 keV). The early failure of the XRS prime instrument left the mission with only two functioning instruments, but this mission is still able to carry out a science program with unique capabilities.

Spacecraft/instrument health & status:
As launched, the Suzaku observatory was equipped with three instruments: the high resolution X-ray Spectrometer (XRS), the X-ray Imaging Spectrometers (XIS), and the Hard X-ray Detector (HXD). The premature loss of cryogen rendered the XRS unusable three weeks into the mission. During that time, however, the instrument performed well and demonstrated that the basic microcalorimeter concept is sound for space applications. The XIS has a contamination issue, but there is some evidence that the cause is understood and that the deposition may be stabilizing. The team has a plan to correct the obscuration, and is currently studying the details in the laboratory. The HXD detector is performing well. After an initial Science Working Group phase, the mission is now a 100% G.I. program in which the U.S. community directly receives 37.5% of the available time, with an additional 12.5% reserved for Japanese-US collaborations.

With the XIS and telescope collecting area comparable to XMM, Suzaku is uniquely well suited to observe extended sources at low X-ray energies. The combined data from the XIS and HXD instruments provide an opportunity for both low and high-energy observations to be performed from a single platform. Although the HXD is non-imaging, its low background enables high sensitivity, particularly for extended sources.

Science strengths:
The primary science goals are to: (1) test the black hole-accretion disk paradigm by studying the Fe K line and reflection components in AGN and X-ray binaries, (2) constrain the contribution to the hard X-ray background due to AGN, (3) survey galaxy clusters out to the virial radius to measure chemical evolution and to infer cosmological parameters, (4) measure the non-thermal emission from clusters as a signature of high energy cosmic rays, (5) constrain the source components of the soft x-ray background, and (6) measure cosmic abundances (CNO) in several environments of the ISM as well as nearby galaxies. The XIS and HXD provide broadband spectral coverage with sensitivity comparable to XMM (for the XIS) and better than Swift/BAT (per unit exposure time, for the HXD) as well as better spectral resolution for both instruments.

Relevancy strengths:
Suzaku is making fundamental contributions to the science objectives of NASA's Astrophysics Division.

Data accessibility:
Suzaku data will be made available through HEASARC, leveraging its existing high-quality archiving and analysis infrastructure. The lag between observation and processed data delivery is anticipated to be of the order of 1 week.

Overall assessment and recommendations:
The Panel is pleased with the 100% GI program on Suzaku and endorses the plan that the team has for addressing the contamination issue with the XIS. We are hopeful that this instrument will be fully utilized as the mission goes forward. Overall, we find that there should be reasonable scientific return and we recommend supporting this mission at levels as close to the proposed minimal level as allowed by the constraints to the MO&DA budget. However, if the contamination issues have not been adequately resolved by the time of the 2008 Senior Review we recommend that continued NASA support of Suzaku be closely examined.

RXTE

RXTE is a versatile medium-to-hard X-ray mission launched in late 1995. Its large collecting area, high scheduling flexibility, unparalleled high time resolution, and broadband spectral coverage, in combination with the ASM being the only medium X-ray (2 – 12 keV) all-sky monitor operating at present and in the foreseeable future, uniquely position RXTE to study the curved space-time near accreting compact objects, the physics of accreting millisecond pulsars, black holes and Galactic and extragalactic jet sources.

Spacecraft/instrument health & status:
All instruments on board RXTE are currently operating at reduced, but scientifically useful productivity. The ASM showed a gradual increase in the proportional counter gain of 10 % per year in one of its units prior to this Senior Review. It is currently operating at ~67 % of its sensitivity at launch. The PCA is now routinely operating with 2 out of 5 PCUs normally active. One of the HEXTE clusters showed a tendency to fail to go into rocking mode when prompted. The respective Instrument Teams have succeeded to substantially slow down the degradation of the ASM and decided to switch to staring mode for HEXTE cluster A, developing a procedure to use the background from cluster B for background subtraction on the cluster A data. All instruments are expected to be able to operate stably for at least another 2 – 3 years.

Science strengths:
RXTE's high time resolution uniquely equips it to study the rapid variability of accreting Galactic compact sources. It has made important contributions to our understanding of neutron star spins and accretion flows in strong gravitational fields. New sources, particularly transients, continue to be discovered each year. RXTE observing time continues to be heavily oversubscribed (by factors of 3 – 4 over the past 5 years), and its data archive is in high demand by the community. The ASM is the only currently operating medium-energy X-ray monitor and is thereby indispensable for triggering of TOOs on flaring blazars and Galactic X-ray transients. RXTE is also well suited to track the synchrotron peak of flaring high-frequency peaked blazars (TeV blazars). The Review Panel was pleased to see that the teams have complied with the 2004 Senior Review recommendation to reduce staff from 28 to 16 FTEs, which appears to be the required minimum for bare-bones mission operation. RXTE will be important for simultaneous hard X-ray coverage in coordinated multiwavelength observations of blazars and flaring Galactic X-ray transients, and for continued X-ray monitoring of such sources. The spectral coverage of RXTE is essential for constraining the underlying continuum in detailed studies of X-ray line profiles from accreting black holes near the innermost stable circular orbit.

Relevancy strengths:
RXTE data address many of the research goals of the previous Structure and Evolution of the Universe roadmap and current overall science objectives of the Astrophysics Division.

Data accessibility:
Data are readily accessible, with the lag-time between observation and production data release having now been reduced to 1-2 weeks.

Proposal weaknesses:
Some of RXTE's previously unique hard X-ray capabilities are now paralleled by those of Suzaku. The team's claim that ongoing RXTE observations were needed for the calibration of Suzaku's high-energy response was not confirmed by the Suzaku team. Generally, given its long (though excellent) track record, many of the future discoveries and results anticipated in the proposal promise to be incremental. Overall, the Panel felt that the science case for HEXTE was the weakest link in the proposal.

Overall assessment and recommendations:

RXTE remains a valuable asset to NASA's space science mission set. It continues to be productive, with continuing substantial interest from the community (in spite of very small Guest Observer grants). The technical problems with the instruments appear to have been dealt with satisfactorily, which should allow stable operations for at least another 2 – 3 years. RXTE has been specifically developed for studying the rapid variability of accreting Galactic X-ray sources, and promises to continue to produce new results on this topic. The overlap with future missions, in particular GLAST and the new generation of ground-based air Cherenkov telescope facilities for TeV studies, supports the case for continued operation of this mission. Its continuous X-ray monitoring, fast slewing, and hard X-ray capabilities make RXTE indispensable for triggering and execution of future multiwavelength observing campaigns on blazars and Galactic X-ray sources. The proposed budget appears to be the absolute minimum for maintaining bare-bones operations, and appears to be a good science-per-dollar value for NASA.

The Review Panel recommends continuing RXTE operation at the requested minimum level for the requested additional duration, i.e. 2 more observing cycles through February 2009. The Panel felt that the science case for HEXTE was the weakest among the three RXTE instruments, and should future budget cuts be unavoidable, these should be targeted at the support of this instrument.

FUSE

FUSE is a MIDEX mission designed to provide spectroscopic access to the rich suite of spectroscopic diagnostics in the far-ultraviolet range.

Spacecraft/instrument status:
The detectors continue to perform well, with only a modest loss in sensitivity since launch. This is a significant achievement for far-UV optics. The FUSE team has done exemplary work in recovering from what seemed like mission-ending failures in the attitude-control system, setting a very high standard in recovering stable pointing over much of the sky by using torque against the geomagnetic field. Nevertheless, pointing is currently restricted to high declinations, a significant restriction in selection of promising targets.

Science strengths:
During the previous years FUSE has been used to address a broad range of science goals, from the reionization of intergalactic He II to stellar winds and coronae. Perhaps its most compelling achievement has been the detection and mapping of the intergalactic medium via O VI absorption. This is a unique achievement, which only FUSE can do at low enough redshifts to avoid confusion with the Lyman α forest and correlate with the galaxy distribution from redshift surveys. This material contains most of the baryons, and possibly most of the metals, in the local Universe. FUSE has entered a phase in which all observations are allocated competitively to the community.

Relevancy strengths:
FUSE contributes to the science defined in NASA's former Origins and SEU themes and current science objectives of the Astrophysics Division.

Data accessibility:
FUSE data are available through MAST. A significantly improved data processing pipeline (CalFUSE3) has been implemented and all FUSE data will be reprocessed within the year.

Proposal weaknesses:
The likely science payoff during the proposed mission extension (2008-2010) seemed merely incremental to the body of observations obtained so far and proposed in the 2006-2008 period. The proposal gave a shopping list of recent science highlights, and might have presented a more compelling case if it had included a small set of science focus areas. Most of the stellar programs, while being worthwhile science, have not led to any unexpected discoveries and have not opened any major new areas of investigation compared to recent advances in other spectral regions. The strongest scientific case is clearly for mapping the intergalactic O VI absorption and additional lines in the extreme ultraviolet seen against quasars at larger redshift. However, suitable quasars require long exposures (of order 200 ksec), so that only about 20 would be added to the archive in the 2-year extension. Compared to the 40-50 such spectra available before 2008, this additional set of data is unlikely to provide significant new insight.

The Panel devoted some discussion to the desirability of continuing FUSE operations into a period when COS might be installed on HST, since the combination of instruments covering the whole UV at high dispersion can be particularly powerful. However, the FUSE team noted that the sensitivity of COS would be so much greater that FUSE would not be able to obtain useful data on the great majority of new COS discoveries.

Overall assessment and recommendations:
In view of the pressure on the MO&DA budget and the modest scientific gain from additional FUSE operations, the Panel recommends that FUSE maintain its current termination date and be funded at a level somewhat below its proposed minimal budget through FY07-08, followed by closeout activities in FY09.